Verifying Radiotherapy Treatment Setup by Interactive Image Registration

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Digital image analysis techniques can be used to assist the physician in diagnostic or therapeutic decision making. In radiation oncology, portal image registration can improve the accuracy of detection of errors during radiation treatment. Following a discussion of the general paradigm of interactive image registration, we describe PortFolio, a workstation for portal image analysis.

INTRODUCTION

Digital radiological images offer certain benefits over images printed on film. Among these are the possibilities of enhancing the intensity contrast of the image appropriate to the clinical task, using computer-assistance in comparing images from sequential studies and combining information from two or more studies for diagnosis or treatment planning.

In radiation therapy, tumor control is sought by irradiating the tumor with high doses of radiation. The entire dose is delivered over a number of fractions over the course of a few days to several weeks. In order to meet the dual goals of treating the tumor with extremely high doses of radiation and sparing the surrounding normal tissues, the radiation beam must be accurately and consistently placed over the tumor. The patient and therapy equipment setup is verified by recording the projection of the beam through the patient during treatment. Such projection images are called portal images. Portal images are compared to images acquired during simulation of treatment, to verify that the treatment plan is being accurately executed. The specific task is to check whether the radiation field overlays the same anatomy in both images (Figure 1). If any errors in the setup are detected, appropriate corrections are applied from the next dose fraction onwards.

When portal and simulation images are acquired on film, the radiation oncologist verifies the accuracy of patient setup by visually comparing the two films placed adjacent to each other on a light box. Portal images can be acquired in digital format by electronic portal imaging devices (EPID). EPIDs are becoming common in clinics now. The contrast of such digital portal images can be improved by using techniques such as adaptive histogram equalization.

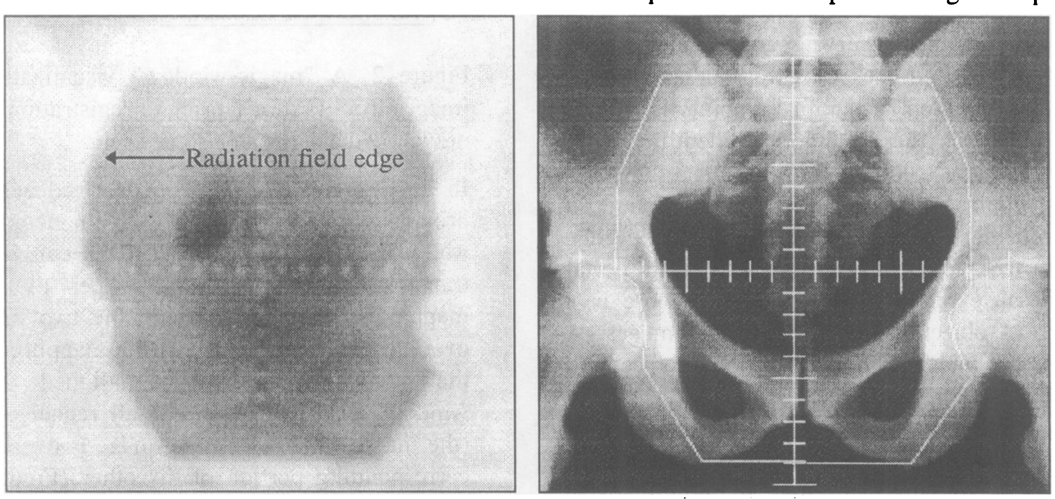

Figure 1. Portal (left) and simulation (right) images of an antero-posterior radiation treatment field in the pelvis. The intensity contrast of anatomical structures in the portal image is poor because of high energy radiation used during treatment.

The setup verification can be done more accurately by using computer-assisted image registration or alignment methods.

In this paper we discuss current image registration techniques, especially for portal imaging. We describe PortFolio as an example of a clinical workstation for image registration. This workstation provides access to images from an object-relational database and image analysis tools for interpreting treatment setup from these images.

IMAGE REGISTRATION

Fiducials are landmark features of the patient anatomy seen in medical images. Interactive registration of a pair of images involves defining the same features on both images, computing a mapping between the features such that the corresponding features are superimposed, and confirming how well the images are aligned.

Defining fiducial features

Fiducial structures for registration must be present and easy to define in both the images, must be stable, and must not deform non-rigidly (e.g. soft tissue). The means by which fiducials are extracted must be invariant to changes in the image such as magnification, rotation, and shifts, and should be insensitive to blurring or the presence of noise. From the user's perspective, feature extraction must involve minimal effort.

Fiducials which have been used include bony landmark points[1], open curve segments along bony edges[2], and the mid-axes or cores[3] of anatomical objects. Identification of landmark points is subject to large errors as these cannot be identified with accuracy in low contrast portal images. Curve segments require more user effort during definition but provide more accurate results. Automatic edge extraction techniques do not work well in portal images because of the poor contrast. A core is a descriptor of object shape in greyscale images. A core is a curve marking the skeleton of an object and has associated with it the approximate width of the object at each location along the skeleton. Cores meet the above mentioned required criteria of features for registration but may require intensive computation. Recent work has led to more efficient ways to extract these features[4]. A user can stimulate the extraction of a core of an object by indicating the middle of the object and its approximate width at that point.

Aligning features

A transformation mapping (shift, rotation, magnification) is computed between the fiducials in the two images which minimizes a distance metric between them[5]. The computed transformation is linear, i.e., the features are not spatially warped. A non-rigid transformation would be detrimental to the task of detecting displacements of the radiation field. The distance metric is selected appropriate to the fiducials being used. In the case of portal and simulation images, the transformation in the fiducials (or equivalently the patient's anatomy) is the error in the patient setup during treatment.

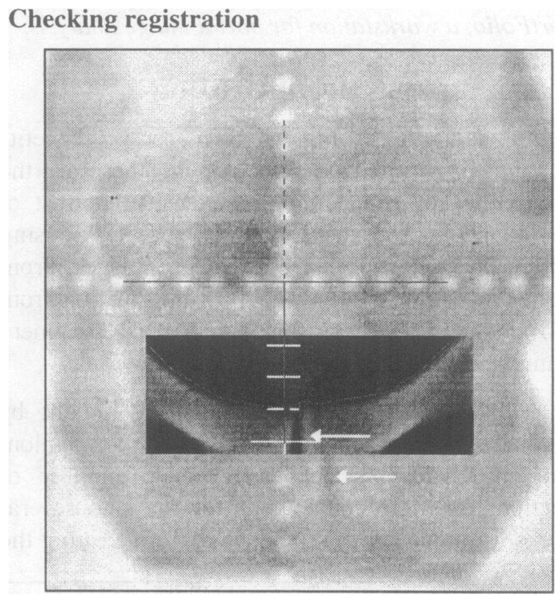

Figure 2. A "magic-window" visualization of the images from Figure 1 prior to registration. Fiducials drawn by the user can also be seen.

In an interactive system, visual feedback must be provided to the user to help them determine how well the images are aligned. This can be done by transforming the fiducials as per the computed mapping and then displaying the two fiducial sets overlaid one on the other. If the mapping is correct, the fiducials should appear aligned. In "magic window" visualization[6], a small rectangular region (the magic window) of one image is overlaid on the corresponding portion of the other (Figure 2). The position of magic window follows the mouse cursor, giving interactive control. When the window intersects the edge of an anatomical structure, a mis-registration shows up as a discontinuity in the edge feature between two images. This is illustrated in the figure where the arrows mark a discontinuity of the bony edges of the pubic symphysis in the portal image and overlaid simulation image. Such a break in an edge may indicate an error in treatment setup.

PORTFOLIO

PortFolio is a workstation for verification of patient setup for radiotherapy. The system runs on standard UNIX workstations. The user interface was developed using OSF/Motif. We used Postgres95 as the database management system[7]. This is an object-relational system which supports SQL and can also store compound data types or objects as are commonly encountered in radiation oncology.

Image access

Given the selection of a patient from the database, a radiation oncologist is presented all the previously *unchecked* portal images sequentially. When the portal image is displayed, a simulation image corresponding to that treatment beam is automatically selected and displayed. The images are displayed next to each other as they would be on a light box. If the physicians need access to other images for the patient, they can be selected from a list indexed by acquisition date and treatment beam.

Image analysis tools

In order to determine the setup error, the user can enhance the contrast of the portal image, define and register fiducials, and visually check the registration using the tools provided.

Portal images enhanced by sharpened adaptive histogram equalization (SHAHE)[8] can improve the accuracy with which physicians can determine treatment setup error[9]. Enhancing the intensity contrast has also been shown to improve the accuracy with which fiducials can be localized[10].

A fiducial editor contains a palette of tools for drawing on an image displayed on a canvas[11]. Using the fiducial editor, a radiation oncologist can define, delete, move, copy, and paste landmark points, curve segments, or object cores. The physician defines corresponding fiducials on the portal and simulation images. When these fiducials are aligned, the mapping is displayed in terms of the treatment setup error - horizontal shift, vertical shift and rotation of the patient. The portal image is transformed by applying this mapping and the resulting image is visualized as an overlay with the magic window or by some other visualization method.

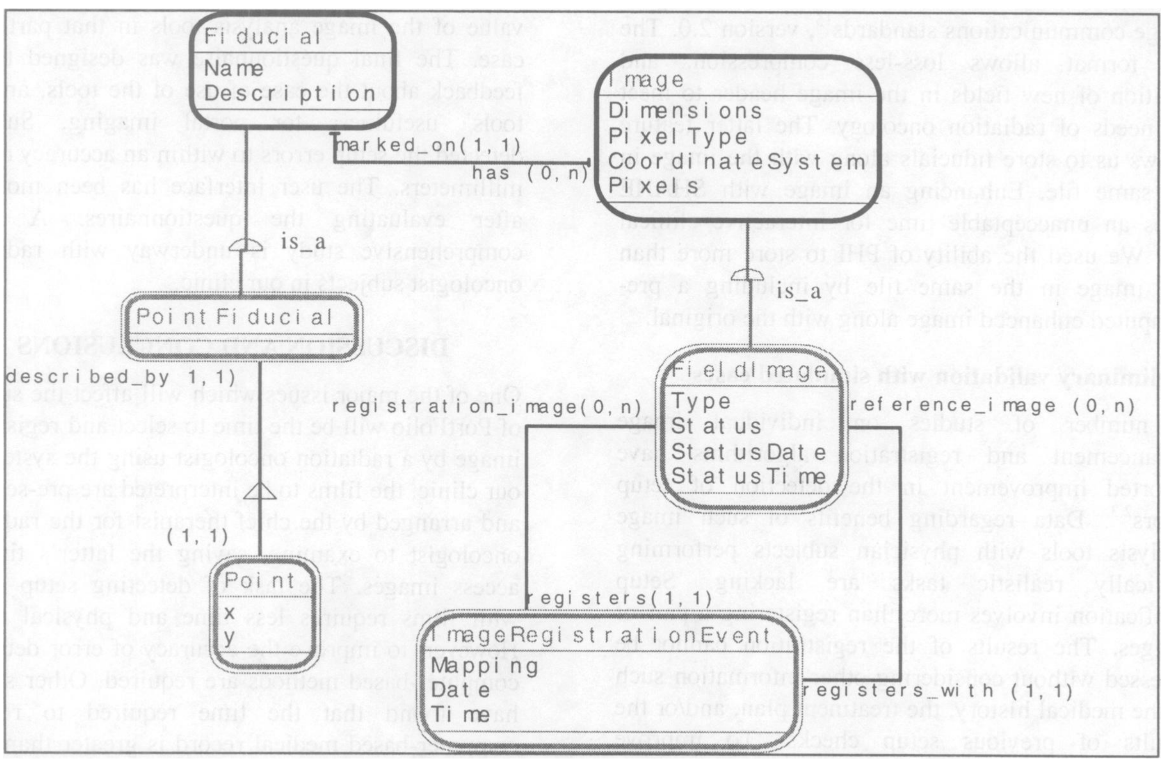

Figure 3. Model of objects involved in registration of portal images.

A medical record for image registration

An object-oriented data model for the different data objects involved in portal image registration was developed. The guidelines proposed by the Joint Working Group for a Common Data Model were followed[12]. Figure 3 shows a partial view of the model of the data entities involved in portal image registration. The *FieldImage* class is a specialization of a general *Image* class for two-dimensional images acquired during radiation treatment. This includes information about the setup verification by the physician. An *Image* may have many *Fiducials* defined on it. The *Fiducial* can be of different types; a two-dimensional *PointFiducial* is illustrated in the figure. Two *FieldImages* along with their *Fiducials* are involved in a portal *ImageRegistrationEvent* which produces the transformation or mapping of the setup error. The model was implemented as a database in Postgres95. PortFolio uses the image access capabilities of UNC/3DCV Image Processing Software[13].

Images are stored in a file format called PHI (Picture-Header-Image)[14]. The fields in this file are accessed by means of keys stored in a data dictionary. The keys used are those defined by American College of Radiology - National Electronics Manufacturer's (ACR-NEMA) digital image communications standards[15], version 2.0. The file format allows loss-less compression, and addition of new fields in the image header to meet the needs of radiation oncology. The latter feature allows us to store fiducials along with the image in the same file. Enhancing an image with SHAHE takes an unacceptable time for interactive clinical use. We used the ability of PHI to store more than one image in the same file by including a pre-computed enhanced image along with the original.

Preliminary validation with simulated cases

A number of studies on individual image enhancement and registration algorithms have reported improvement in the detection of setup errors[2,3]. Data regarding benefits of such image analysis tools with physician subjects performing clinically realistic tasks are lacking. Setup verification involves more than registering a pair of images. The results of the registration cannot be assessed without considering other information such as the medical history, the treatment plan, and/or the results of previous setup checks. To improve PortFolio and to ascertain the benefits of the system, we are planning to conduct a series of studies. The first set of studies will explore the impact of PortFolio on the accuracy of setup error detection, and the usability of the workstation in the clinic.

To begin, a radiation oncologist from another institute was invited to critique PortFolio. Following a training session, he registered three portal images with their corresponding simulation images. This evaluation resulted in a list of suggestions to improve the performance and usability of PortFolio. The most significant of the criticisms was the increased time and interaction required as compared to working with a portal film.

A pilot test of the system was conducted with three clinical physicists. Each subject registered four portal images of an antero-posterior pelvic field with a simulation image. These images were reconstructed[3] from the high resolution Visible Human CT dataset from the National Library of Medicine. A treatment plan was designed by a radiation oncologist. Setup errors were simulated in the delivery of the radiation beam and portal images were reconstructed with these known errors. The subjects were free to choose the tools they needed for registration. There were no time restrictions for the task. They were required to fill out a questionnaire after each image registered and at the end of the study. The first questionnaire inquired about the value of the image analysis tools in that particular case. The final questionnaire was designed to get feedback about the ease of use of the tools, and the tools' usefulness for portal imaging. Subjects detected the setup errors to within an accuracy of two millimeters. The user interface has been modified after evaluating the questionnaires. A more comprehensive study is underway with radiation oncologist subjects in our clinic.

DISCUSSION AND CONCLUSIONS

One of the major issues which will affect the success of PortFolio will be the time to select and register an image by a radiation oncologist using the system. In our clinic, the films to be interpreted are pre-selected and arranged by the chief therapist for the radiation oncologist to examine, saving the latter's time to access images. The task of detecting setup errors with films requires less time and physical effort. However, to improve the accuracy of error detection computer-based methods are required. Other studies have found that the time required to read a computer-based medical record is greater than for a paper chart[16]. The user interface must be designed to reduce the effort and to present information in a manner such that the time required for the task is decreased[17]. We are making efforts to find ways to simplify the user interaction and reduce total time required to register an image. Enhancing the contrast in images may make it easier and quicker for the user to define a fiducial. Since a portal image is acquired frequently for the same treatment field, many portal images correspond to the same simulation image. After the user defines fiducials on the simulation image once, the same fiducials are presented with the image at the next registration. Another way to reduce the time is to pre-register the images automatically and present the results to the physician to confirm visually.

Image enhancement and registration techniques have been demonstrated to assist the physician in making more accurate decisions for verifying treatment setup errors. Digital images stored in a database as part of the patient record can be accessed conveniently and quickly. The benefits that this technology provides in enhancing clinical decision making could justify the cost of picture archiving and communications systems for radiation oncology.

Acknowledgments

We would like to thank Julian Rosenman, Dan Fritsch, Suraj Raghavan, Graham Gash, Larry Marks and Jean-Michel Leon for their help with this project.

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